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SEMIANNUAL REPORT ON
CONTROL SYSTEMS STUDIES

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ABSTRACT

This report summarizes progress in Control Systems Studies, PROJECT PLAN 165-35,* covering the period of accomplishment from 1 July through 31 December 1960, as planned for performance under Contract AF 04(647)-619. ~~The technical~~ progress [redacted] is divided into ~~four~~ 4 sections covering the following divisions of [redacted] effort: (a) Advanced Control System Circuit Development, (Test Vehicle No. 2), (b) Circuit Reliability Studies, (c) Digital Control System Circuit Development, and (d) Hot Gas Servo Studies. ~~In connection with the work~~ on Test Vehicle No. 2, the development, testing and present status of the signal processing and power supply circuitry for use in connection with the MIG gyros is described. Also, the results of environmental and life testing of the printed circuit timer-programmer and the status of the welded circuit timer-programmer are presented. Under Circuit Reliability Studies, some preliminary results of a study of the application of redundancy to both digital and analog circuits and ~~certain of the~~ work on circuit failure analysis using component failure rate data is described.

The development of digital control system circuitry is described, specifically that circuitry applicable to a digital autopilot system and certain circuitry developed for use with advanced programmers and function generators.

The work in the hot gas servo area consisted of the preparation of test plans and the performance of testing on General Electric's hot gas servo.

Technical plans for the next six months of activity in Control Systems Studies are presented, as is a bibliography of documents and reports pertinent to the work described.

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*"Project Plan No. 165-35, Control Systems Studies." 7431.2-294.

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ILLUSTRATIONS

I. INTRODUCTION AND BACKGROUND

This report is a summary of the activities comprising Control Systems Studies for the period 1 July to 31 December 1960 This program is defined by PROJECT PLAN 165-35 and is performed under Contract AF 04(647)-619. The material presented here is intended as a synopsis of the technical activities; details of this work may be found in the documents referenced in the text and listed in the bibliography.

The Control Systems Studies Program originally a portion of what was known as the Advanced Circuits Laboratory Program, was initiated in July 1957 under Contract AF 18(600)-1190. with the following objectives: a) to support with a laboratory capability the system engineering and technical direction of ballistic missile control systems; b) to study advanced control system components and equipment in order to reduce weight, size and power consumption and to improve performance and reliability; and c) to investigate specific weapon system controls problems as they arose and to generate quick fixes when necessary. In June 1958, a new program plan. entitled Computer and Control System Studies and numbered 165-17 was submitted, expanding the original objectives to include studies of digital computer components as applied to ballistic missile systems. The activities outlined in this program plan were later separated into two programs: Control Systems Studies, Project Plan 165-35. and Computer Systems Studies. Project Plan 165-36.

The activities of Control Systems Studies are now divided into three general areas Electronic Circuits, Control Sensors, and Power Servos. A summary of the accomplishments in these areas as reported in the last semiannual report (STL/TR-60-0000-09204) will aid in an understanding of the work in progress

In the area of electronic circuits. signal processing and power supply circuitry for MIG gyros was designed and developed; regulators and high-powered static inverters were investigated; and various types of static switching circuits were built and tested. In addition. a program aimed

at developing design techniques for increasing the reliability of control system electronic circuits was inaugurated.

Laboratory work in the control sensor area included the evaluation of the MIG (GG87) gyro, the testing of the Minuteman angular accelerometers, and a study of methods of spin motor monitoring.

Work in the power servo area included a state-of-the-art survey of hot-gas servos, evaluation of a magnetic clutch actuator, hydraulic fluid contamination studies, and testing of the Minuteman nozzle-control unit servo.

Due to a reduction in the research and experimentation effort carried out in connection with ballistic missile systems engineering and technical direction, a significant reduction in the level of effort applied to Control Systems Studies occurred during this report period. As a result, it was necessary to terminate certain of the studies under way and partially reported on in the last semiannual report. Specifically, the studies in connection with the development of high-powered static inverters and converters, the testing of angular accelerometers, the investigation of the operating characteristics of primary and secondary batteries and fuel cells, and the testing of advanced servo actuators and the Minuteman nozzle control unit were discontinued during this period.

II. TECHNICAL PROGRESS

A. Test Vehicle No. 2

The program of development of advanced circuits for control system applications, which has been carried on as a joint program with the Product Engineering Department as "Test Vehicle No. 2" (TV-2), has progressed further toward completion during this report period. This program, consisting of two portions, the development of control system signal processing circuits (TV-2G) and the digital timer programmer development (TV-2P), has met with success in all areas. When undertaken, it was felt that these studies would contribute materially to the weapons systems programs for future missile and space applications. It was intended that the most advanced concepts be investigated, both in circuitry and in packaging techniques. As a basis for the development, the Minneapolis-Honeywell GG87 MIG gyro was chosen as the control sensor. The present status of this program is indicated in the following sections. Additional material on this program can be found in previous semiannual reports on Control Systems Studies, STL/TR-59-0000-09933 and STL/TR-60-0000-09204.

1. Gyro Circuits (TV-2G)

This portion of the TV-2 program consists of the testing of the GG87 MIG gyro, of the development of compatible control and signal processing circuitry for use with the gyro, of the development of advanced power supplies, drive circuits, etc., suitable for advanced control system use, and of the packaging by advanced concepts of the gyros and circuitry. The packaging of these circuits has occupied the major amount of time during this report period and is covered in the report for Components Packaging Techniques studies under Project Plan 165-21.

a. Circuit Design and Development

Most of the circuits were designed during the previous report periods and were described in detail in the appropriate reports.

Activity during this period in this area has been confined to the extensive testing of the circuits and improvements where performance was found to be lacking. It was determined that the choice of a 4.8-kc carrier frequency led to some problems in the modulators and demodulators because of shunt winding capacity. It has generally been decided that a lower frequency, perhaps about 3 kc, would be more desirable, although a change at this state of development would not be practical. This change would result in approximately the same savings in transformer size as is effected by the use of 4.8 kc and would reduce phase shift and other problems.

An evaluation of the performance of the torquing, caging, and command circuits has revealed that the energy content of each pulse produced by the pulse torquing circuit is not sufficiently constant as a function of temperature and input voltage to produce the improved performance originally contemplated. Other pulse torquing schemes have suggested themselves, and are currently being investigated from an analytical standpoint.

Circuit descriptions of all circuits were given in the last report and these, with minor exceptions, are still applicable. In general, all of these circuits have now been packaged as welded electronics modules and are now undergoing module testing. A number of these modules have been electrically tested with satisfactory results.

b. Gyro Testing

Testing of the MIG gyros for use in TV-2 continued during this reporting period. In addition, effort was expended in the detailed documentation of the results of the drift tests performed earlier.

The a-c torque motor in MIG S/N J-1 was calibrated in equivalent gyro torque per milliampere^2 (dyne-cm/ma^2). These windings are normally used to compensate the gyro for fixed drift; however, in this case, the low scale factor (0.02 dyne/cm/ma^2 = 0.04°/hr/ma^2) makes it very useful as a method of evaluating low level residual signals at the output of TV-2 type pulse torquing gates. This technique will be used in the environmental qualification of the prototype TV-2 gyro reference assembly.

Signal generator elastic restraint has been measured on MIG S/N J-2. The restraint was measured as a function of true gimbal angle. The average restraint was $0.208^{\circ}/hr/^{\circ}$gimbal. For the gyro tested, this corresponds to about $0.1^{\circ}/hr/^{\circ}$input.

An apparatus was devised which allows continuous plotting of speed versus torque for gyro wheels from near zero velocity to synchronism. The apparatus will not, unfortunately, plot stall torque. A TV-2 type three-phase quasi-square-wave wheel supply will be available for testing with the device early during the next report period.

c. Packaging and Status

Most of the circuits have now been packaged as welded electronic modules and these modules are now being individually tested. The gyros and the torquing circuits are contained in one package (shown in Figure 1), while the remainder of the signal conditioning, shaping and power supply circuits are contained in another package (shown in Figure 2). The two-package concept was used to facilitate the thermal design. The two packages are interconnected by a single cable and all other connections (inputs, outputs, test connections, etc.) are made to the electronics package by means of four connectors.

The castings of both packages are of cast magnesium construction. These castings are presently being machined. All parts are on hand and construction of both packages is proceeding on schedule. It is expected that the packaging will be completed in February 1961.

d. System Testing

Planning is now under way to formulate test procedures for the testing of two completed packages so that complete electrical system tests can begin as soon as the packages are completed. After adequate electrical performance is assured, type testing will take place, subjecting the units to temperature, shock, vibration, etc., to assure the validity of the mechanical and thermal design. Any necessary corrections will be made as deficiencies are apparent.

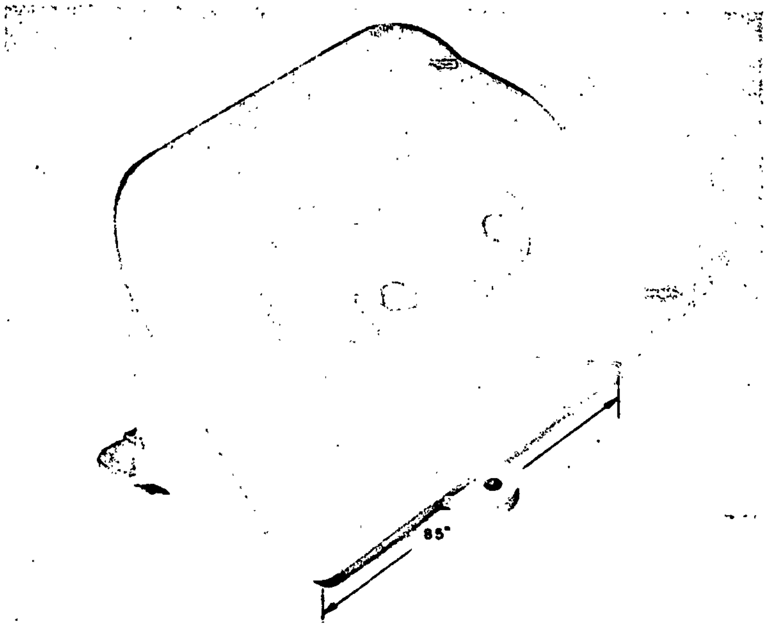

Figure 1. TV-2G Gyro Package.

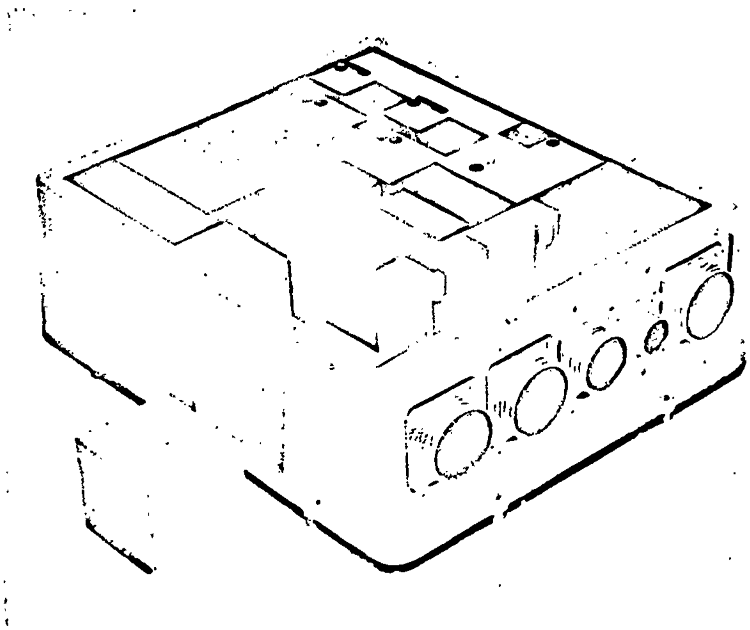

Figure 2. TV-2G Electronic Package Mockup.

b. Environmental Testing

Environmental type tests were performed on the first printed circuit timer-programmer delivered by the Product Engineering Department. During the vibration phase of the testing sequence, the unit experienced eight mechanical failures such as broken wires and broken mounting brackets. All failures were repaired, minor design deficiencies were rectified, and the vibration tests were started over; the unit successfully passed all of the tests contained in the "Environmental Type Test Specifications for Test Vehicle No. 2 Laboratory Study Electronics Equipment Components," D 8645. Only during the vibration phase of the type test were mechanical failures noted, and at no time during any of the environmental tests were any electrical failures observed.

c. Life Test Results

A life test involving two ten-stage binary counters identical to the units used in the timer-programmer ("Circuit Design for a Digital Timer-Programmer," STL/TN-59-0000-00357) was conducted for a period of 7 months. The twenty stages have operated continuously, failure free, for 5000 hours. This represents a total of 100,000 component hours. This test is one of several whose purpose is to compare calculated circuit failure rates with actual laboratory data. Based on published component failure rate data, the probability of failure-free operation in a laboratory environment of the twenty binary stages for 5000 hours is 0.88. For this test the two counters operating in parallel were started from a reset condition in order that the outputs of the counters could be compared, stage for stage, at the end of each week to determine if any malfunction had occurred. The occurrence of a counter malfunction would have been indicated by nonidentical counts held in each ten-stage register. The contents of the registers were compared by removing the common input clock pulse and checking the condition of each of the twenty binary elements.

Modifications to an existing laboratory autopilot test console to make it compatible with the TV-2 autopilot have begun. Use of an outboard matrix will minimize changes to the console. An adapter plate is being fabricated which will allow use of an existing holding fixture for positioning the TV-2 gyro reference assembly on a test table.

2. Digital Timer Programmer (TV2-P1)

a. Packaging and Status

Two printed circuit timer-programmers fabricated by the Product Engineering Department were delivered to Controls Equipment Section for evaluation. Both units have successfully passed the electrical tests contained in the document 7431.2-353, "Electronic Digital Timer-Programmer Electrical Acceptance Test Procedure." In addition the units have been subjected to environmental and life tests. Figure 3 is a photograph of the completed printed circuit timer-programmer with the cover removed.

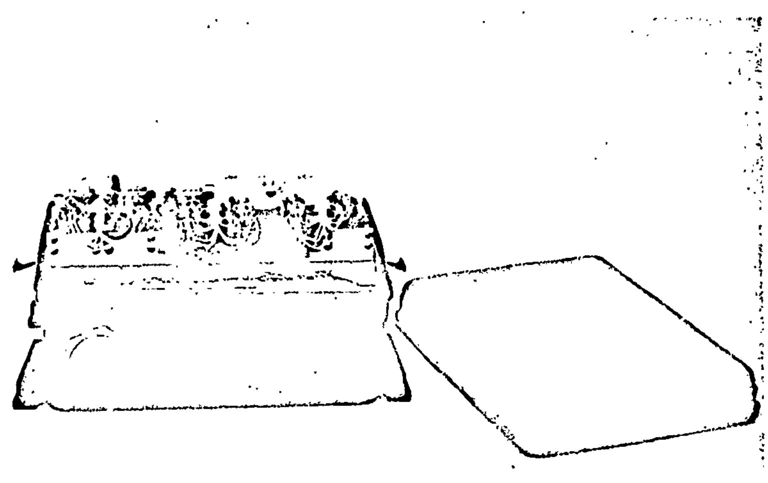

Figure 3. Printed Circuit Digital Timer-Programmer (TV-2P1).

The life tests which have been conducted on the entire printed circuit timer-programmer were halted on 21 December 1960 due to a diode failure located on one of the matrix boards. The timer-programmer at this point had operated continuously, failure free, for 2100 hours. This diode failure represents the first component failure during the extensive environmental and comprehensive bench testing period, or during the various life tests which have been performed on the timer-programmer circuitry.

3. TV-2-P2

a. Packaging and Status

The welded wire model of the digital timer-programmer, a mockup of which is shown in Figure 4, will be delivered for test to the Controls Equipment Section of 13 January 1961. To date, the twenty-one stage counter, the trigger shaper module, shown in Figure 5, the relay driver modules, and the interconnecting matrices have been fabricated and tested by Product Engineering Department personnel. The diode matrix configuration has been submitted to the Product Engineering Department for proper diode placement on the matrix cards.

The first welded wire timer-programmer is scheduled to be delivered to the Controls Equipment Section for test and evaluation on 13 January 1961.

b. Testing

To expedite the testing of this unit the test equipment used for testing the printed circuit timer-programmer has been modified such that both the printed circuit and welded wire timer-programmers are now compatible with the test equipment. A rough draft of the electrical acceptance test procedure to be used with the welded wire unit has been written and will be used in the testing of the welded wire timer-programmer.

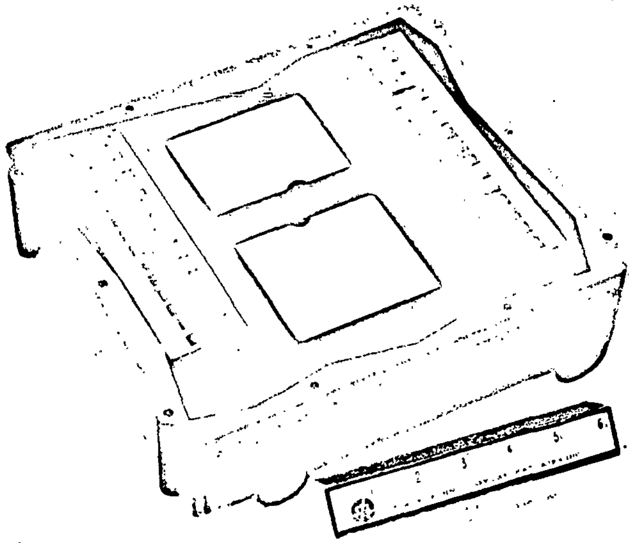

Figure 4. Mockup of Welded Circuit Digital Timer-Programmer.

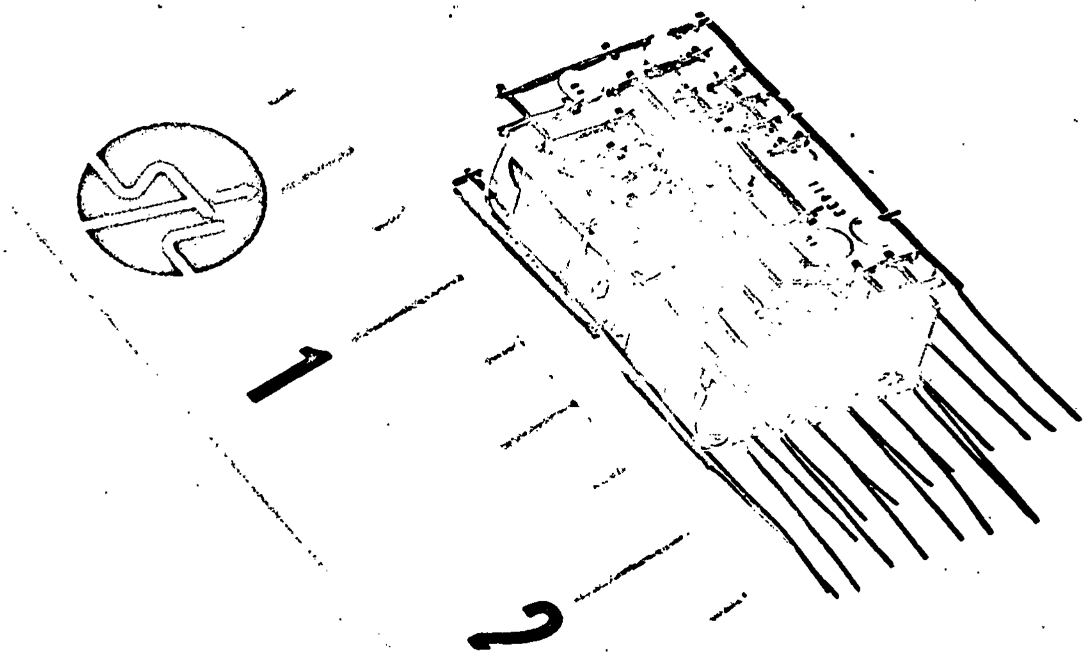

Figure 5. Welded Circuit Module (Trigger Shaper) for TV2-P2.

B. Circuit Reliability Studies

These studies were undertaken to provide practical experience in techniques for the improvement of reliability of control system electronic circuitry. The approach has been to evaluate the reliability of existing advanced circuits through life testing and to seek improvements through the application of derating techniques, simplification in design, use of digital techniques, and the application of redundancy.

1. Application of Redundancy

Considerable literature has discussed the merits of redundancy to the improvement of reliability, but very little has been done in the realm of actual application of these theories. Although redundancy may be theoretically applicable, it is often very difficult, if not impossible, to apply it successfully to actual circuits and devices. The approach taken in the study of the application of redundancy has been to first assimilate the existing literature (see below), then to try the actual application of redundancy to the simpler circuits, starting with digital circuits and working on into the more difficult analog circuits. In general, it appears to be possible to apply redundancy to purely digital circuits such as flip-flops and gates. Several different approaches were reported on in the report, " An Improvement in the Reliability of Digital Circuitry Through the Application of Redundancy," STL/TN-60-0000-19221. In general, it was noted that the application of part redundancy to these circuits results in the greatest increase in reliability, but with the penalty of greater difficulty of checkout, over the application of circuit redundancy.

In the case of analog or analog-digital circuitry such as amplifiers, motors, power supplies, trigger circuits, modulators, integrators, etc., the solution is not simple and in many cases may not exist. A report is presently in preparation which will show ways in which some of these circuits may be made redundant, but in no case with the ease or with the improvement in reliability that was apparent in the case of the digital circuits. For some cases, no techniques have been found. Work will continue in these areas with hope of eventual solutions.

2. Reliability Bibliography

A literature survey, "Circuit Design Reliability Through Redundancy," STL/AB 60-5111-38, has been prepared by the Technical Information Center, Literature Research Group in response to a request from the Controls Equipment Section. This document is intended to be used in conjunction with investigations into various methods of increasing circuit and system reliability. System as well as circuit reliability is discussed in the various articles. Much attention is given to redundancy as an effective means of increasing the overall reliability.

3. Circuit Analysis Using Failure Rate Data

In connection with the TV-2 programs (see Section A), an avowed purpose of the studies was to improve the reliability of all circuits through the application of all reliability improvement techniques short of redundancy. The most significant of these was proper derating of components. It has been shown that the life of components is significantly increased if the part is operated under low stress conditions. These conditions include not only the environment of temperature, vibration, etc., but also the voltage, current or power that the component is subjected to. Vibration and, to a lesser extent, temperature may be lessened through proper mechanical design. It remains for proper electrical design to reduce the electrical stresses. This may be done by designing the circuitry so that excessive amounts of power are not present and the voltage levels are low. For instance, it is possible to design a flip-flop to operate at an average power level of 1 watt or at an average power level of 1 mw. The latter case will be far more reliable, as well as smaller, more efficient, etc.

To aid in the proper derating of components, derating sheets have been devised for parts such as transistors, diodes, resistors, capacitors, transformers, etc., with derating guide ules contained thereon to guide the circuit designer in the choice of parts. These derating sheets have been used on all parts used in the TV-2 program and all parts

stresses are now sufficiently low that further lowering would result in only a negligible increase in reliability. Circuit analysis has also been done on all the circuits, and their individual and combined failure rates have been estimated. From this, estimates have been made of the failure probabilities for various lengths of time and type of mission. An attempt will be made to confirm these estimates through extensive life testing.

A report is being prepared concerning increasing the mean-time-between-failure (MTBF) of the digital timer-programmer through applications of redundancy. Using component failure rate data published by BTL and RCA, the MTBF for the timer-programmer was calculated to be 12,000 hours. Mathematical calculations have shown that designing for redundant components, to the extent that the total number of parts is increased by a factor of 2.5, will result in an increase of the probability of successful operation for one year in a laboratory environment from 0.44 to 0.94. The increase in reliability for a given period of time is obtained, in this case, by a "majority-rule" redundancy scheme. This scheme is essentially one of three identical units operating in parallel into a decision matrix. In the event that one of the three circuits fails, the device will still continue to operate, regardless of the mode of failure, due to the logic involved in the decision matrix. In some failure conditions, successful operation will be obtained even when two of the three circuits fail. This condition, however, is dependent upon the mode of failure of the two non-operating circuits.

Since the MTBF for the timer-programmer is 12,000 hours, employing no redundancy, it is reasonable to expect a probability of successful operation in a missile launch environment considerably in excess of 0.99.

Part of the redundancy investigation has been a review of basic concepts, and an attempt to reconcile the mathematics of redundancy with the reality of presently available circuit elements. The mathematics of redundancy are well documented but provide little assistance in circuit

design. Digital circuits offer the most promise for applications of redundancy. Redundancy applied to analog circuits is a very formidable problem that has not been completely solved. Three-terminal active elements are difficult to use in a redundant array because of the interaction among the three terminals. Since the internal node of the three-terminal active element that is used in equivalent circuits does not exist per se in the device itself, redundancy at this level is not possible. Thus, the two-terminal mathematics is of little help in dealing with three-terminal devices.

A transistor is the worst offender with respect to interaction among terminals, and hence the most difficult to use redundantly. Vacuum tubes and magnetic amplifiers exhibit much better isolation between input and output circuits. It would seem that magnetic amplifiers show the most promise, and investigations are anticipated in this field. Another approach that will be investigated is the use of two-terminal negative resistance devices in redundant modes for digital circuits. Shockley diodes and Esaki (tunnel) diodes are two examples of two-terminal negative resistance devices.

It is easy to show why it is desirable to apply redundancy at the component level. Consider two identical elements connected in parallel, each with a failure probability of q. Assume that the network will perform satisfactorily if one element has failed. The network failure probability, Q, in terms of the element failure probability, q, is

$$Q = q^2$$

If R is defined as the ratio of element failure probability to the network failure probability, then

$$R = \frac{q}{Q} = \frac{1}{q}$$

As q becomes smaller, the profit realized with redundancy increases. In a way this is unfortunate because the less an element needs redundancy,

the more redundancy helps. This means that redundancy is most effectively applied at the level where the failure probability is the lowest, which is on the component level. The results obtained using the simplest configuration are true in general, and more elaborate networks show a spectacular improvement with redundancy as the element failure rate approaches zero.

4. Life Testing

Life tests have been conducted on the relay counter* employing a CHEN Counter for initial frequency division of a clock pulse source and relay flip-flops for low speed frequency division. This relay counter has operated continuously, failure free, for the past six months. On 29 December 1960, the least significant bit of the twelve-stage relay counter completed 2.5 million cycles. The magnetic latching relays used in this counter are guaranteed by the manufacturer for only 0.1 million cycles. The life tests are being continued.

C. Digital Control System Circuit Development

Several advanced programs were initiated during this report period in the field of digital control circuits. Digital circuits have been chosen for investigation because of several inherent advantages they have over analog circuits. They are intrinsically more reliable and may in general be made to have any desired degree of reliability through the application of redundancy techniques. They are more efficient of power in that all components are operated in a switched mode. They may be made smaller by several orders of magnitude since there are no capacitors or transformers of certain irreducible size, and because the techniques of microminiaturization are easily applied. For example, there now exist on the market flip-flops of only about 0.01 cubic inch size. In addition, in many cases they are more accurate. Drift is no problem and the accuracy may often be extended to any desired degree.

Studies initiated during this period included: digital autopilot circuitry, advanced programmers, and certain other digital function generators and multipliers.

*"Circuit Design for Low Energy Relay Digital Timer." STL/TN-60-0000-09035.

1. Digital Autopilot Circuitry

It appears to be possible to provide digital circuits which will accommodate most of the normal analog autopilot functions and in the process improve reliability, accuracy, size, weight, and efficiency. Using a Minneapolis-Honeywell GG49 MIG gyro as the controls sensor, circuitry is being designed and breadboarded to accomplish these objectives. Figure 6 is a photograph of the breadboard of these circuits. The gyro will be

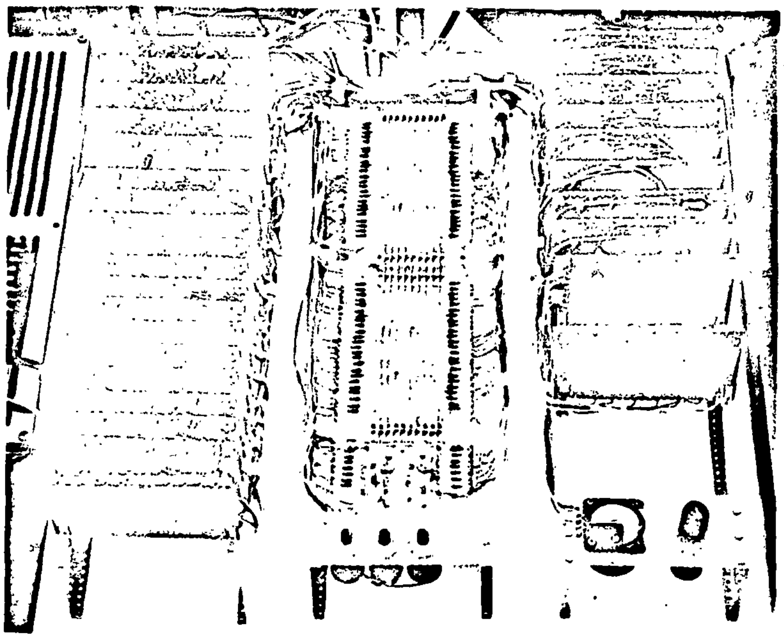

Figure 6. Breadboard of Digital Autopilot Circuitry.

operated at all times in a rate mode, with the rate information obtained by an analog-to-digital converter operating into a rate register, and with the position information being obtained by differential counting (numerical integration) of the pulses torquing the gyro. A new concept of pulse torquing will be used to provide constant pulses. The rate and position information will be combined digitally, eliminating the shaping networks. This alone will account for a large size reduction. The output will be capable of driving hydraulic or pneumatic servo valves or controlling bang-bang valves by

digital pulse modulation. The power supplies will also be of an advanced type, building on the TV-2 experience. An attempt will be made to eliminate all large capacitors, chokes and transformers from the design so that the circuitry will in all respects be suitable for microminiaturization.

At this time the rate and position registers are completed, together with the analog-to-digital converter and the logic circuit for adding the contents of the two registers. This circuitry has been tested with a number of pneumatic valves and operation appears to be satisfactory. The power supplies and torquer circuits are about half completed. One complete channel will be built and it is planned that the testing will completely prove the concept.

2. Advanced Programmers

An advanced programmer, breadboards of which are shown in Figures 7 and 8, has been assembled using core-transistor-logic (CTL) building blocks manufactured by DI/AN Controls, Inc. This particular configuration has a single output, but the timing interval can be set in remotely in the form of a serial binary word. This type of circuitry should have application in programming devices requiring the ability to be set remotely by means of a radio command link.

Figure 9 is a block diagram of the programmer. The binary word representing a time interval, or number of timing pulses, is loaded into the shift register. The timing interval begins with the receipt of the start count signal. Each subsequent timing pulse triggers the burst generator. The number of pulses in the burst is equal to the number of stages in the shift register, and the repetition rate of the burst pulses is determined by a local oscillator or, if available, a system clock pulse generator. The burst pulses are used as shift pulses in the register and half-subtractor. Thus, a burst of pulses circulates the word in the register, and the half-subtractor subtracts one from the number in the register. When the subtractor has depleted the number stored in the register, an output pulse is generated.

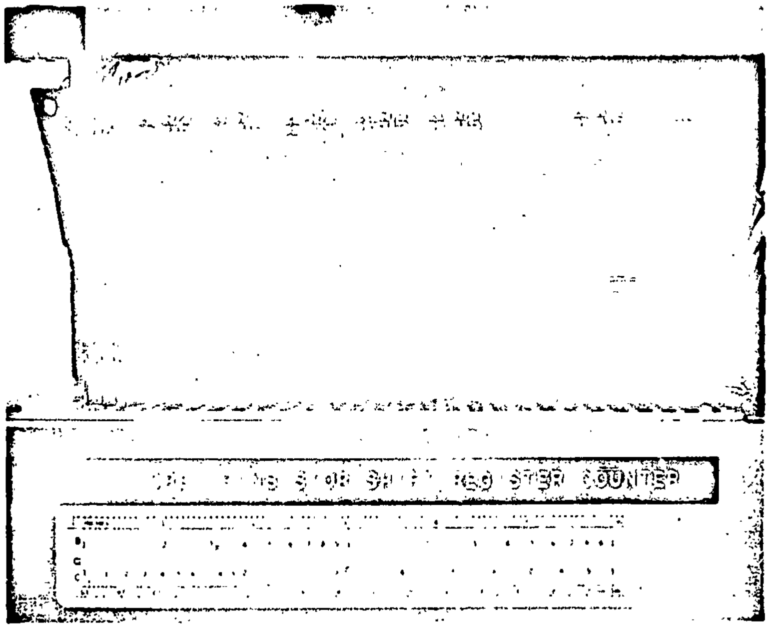

Figure 7. Core-Transistor Logic Elements.

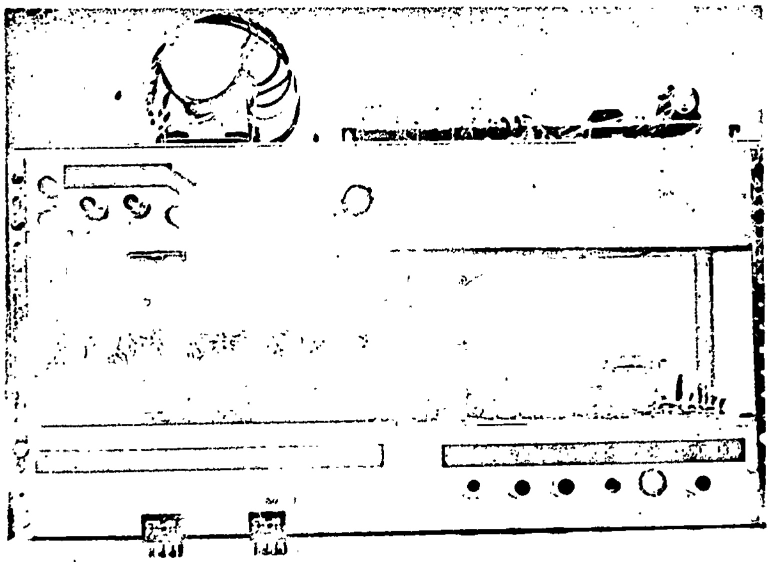

Figure 8. Breadboard of Advanced Programmer using Core-Transistor Logic Elements.

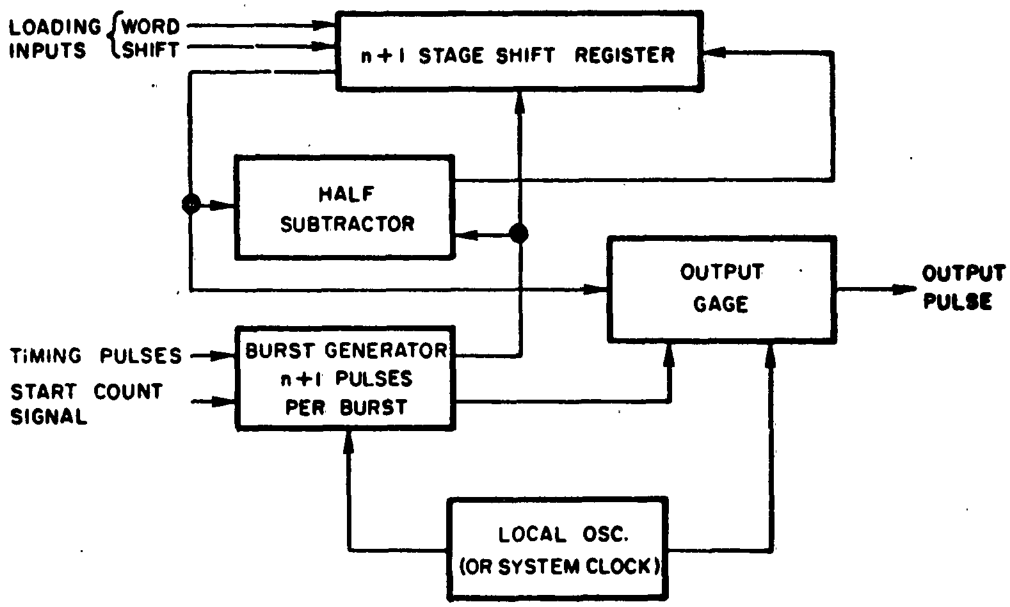

Figure 9. 2^n Counter with Remotely Controlled Interval.

The count capacity of a programmer with n + 1 elements in the shift register is 2^n. The local oscillator may be any frequency up to 100 kc (1 mc with special units), and the timing pulses must be spaced far enough apart in time to give the burst pulses time to circulate the number.

The CTL element has a nonvolatile memory that will survive power failures. It is very insensitive to radiated noise and power supply noise. It requires only one power supply voltage and dissipates a fraction of the power used by transistor flip-flops. The CTL does not have the maximum frequency of operation of a transistor flip-flop, nor does it have the continuous read-out feature. When the core is interrogated, the read-out is destructive.

In applications such as the one described, the CTL has outstanding advantages over the transistor flip-flop. A memorandum is under preparation that treats the CTL in some detail.

3. Function Generators and Multipliers

For some of the advanced control systems now under consideration, it will be necessary to have stored functions of time which, upon initiation, give a single-valued output that may be of any general shape. The initial considerations of this problem indicate that two general approaches appear suitable. The first is a conventional analog computer function generator approach, wherein diodes are biased to particular break points and series resistors control the slopes. A number of segments of straight lines thus determine the function. The disadvantages of this method are the relatively large number of operational amplifiers needed and the difficulty of obtaining a family of curves or a number of functions selectable from the ground.

The other approach and the one that appears more promising uses a digital counter driven from a standard frequency source. Diode gating causes discrete digital current steps to be summed into an integrator in a preset way. The integrator causes the steps to be converted to ramps and thus produces the function by straight line approximations. Several different sets of diode gates are easily used with a remote selection. For either technique about 30 segments would be adequate. A multiplier may also be necessary for certain advanced control systems under consideration. This problem has not as yet been completely solved, but it is felt that a wholly electronic approach is necessary. Here again, the initial approach will probably be to duplicate an analog computer electronic multiplier with transistor circuitry. Much further study is necessary on this problem.

D. Hot-Gas Servo Studies

The power servo studies consist of a program to study the application of hot-gas servo-actuators for thrust vector control of missiles. Hot-gas systems appear to have some advantages over conventional hydraulic systems. In the important areas of reliability, they should have better storability and contamination insensitivity properties, and they should bear up under more severe environmental conditions,

especially elevated temperatures. The major deficiencies seem to be a result of their lack of general usage; namely, an adequate mathematical representation is needed. Also, the general lack of operating experience results in a lack of high confidence test and performance information. The studies undertaken aim to overcome these deficiencies and, more specifically, aim to look into specific ballistic missile application of hot-gas servos.

As indicated in previous reports, a state-of-the-art survey has been made, cold-gas test facilities have been designed and built, a General Electric hot-gas servo has been procured for test, and initial studies have been made.* During this report period, a detailed test plan of the General Electric hot-gas servo was prepared and testing initiated.** Figure 10 is a photograph of the hot-gas servo test set up. The initial test consisted of a

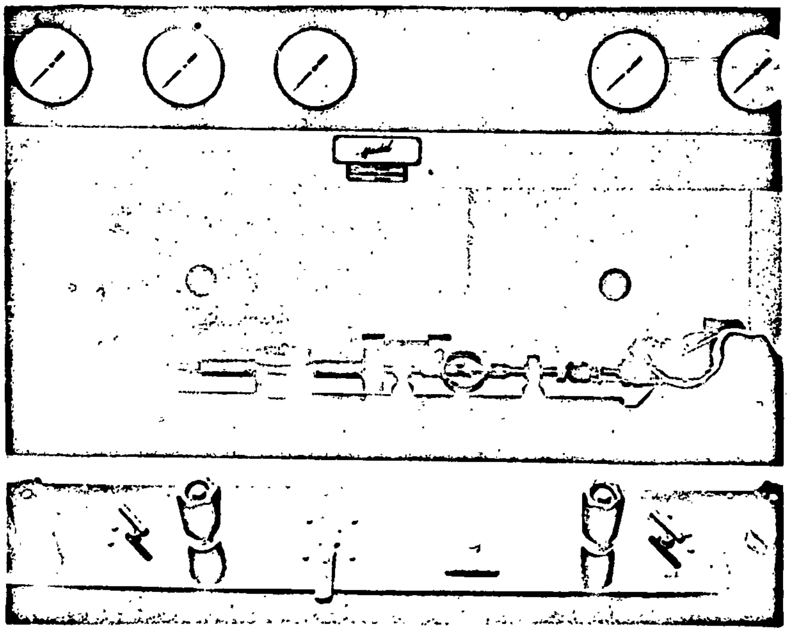

Figure 10. Hot-Gas Servo Test Setup.

*Tsusaki, W. "Hot Gas Servo-Actuator Program." 7431.2-365. 16 November 1960.

**Tsusaki, W. "Test Plan - Laboratory Investigation of General Electric Hot Gas Servo System." 7431.2-365. 9 November 1960.

checkout of the unit for compliance to our specifications. Gains were determined and some unloaded frequency response runs were made. At present, loaded frequency response tests are beginning. Just prior to the loaded frequency response runs, the unit was completely checked and the associated amplifiers and instrumentation reset and calibrated. This was necessary because of the time lag between the initial and present tests. The frequency response tests will be run on a load fixture with the loads approximately that of the third stage nozzles of Minuteman. Initially only the spring and mass will be used, then the coulomb friction component will be added. Open and closed loop runs will be made, both with and without the coulomb friction. The object of the frequency response and other testing is to compare experimental data with the results of the analytical studies which have been made.* The results obtained will determine the areas in which the future testing will be concentrated. A more accurate mathematical model will be the result of this series of tests.

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*Rieman, F. C., and W. Tsusaki. "Investigation of a Linear Model of the General Electric Hot Gas Servo System." STL/TM-60-0000-00035. 14 April 1960.

III. TECHNICAL PLANS

The following section lists technical plans for the next six months of activity in Control Systems Studies. The various items of work are listed under the same headings which are used in the body of this report.

A. Test Vehicle No. 2

It is planned to complete the electrical and environmental testing of the two packages of TV-2G. These packages contain the three MIG gyros, signal processing circuitry, and power supply circuitry. During this period it should be possible to perform a complete type test on these units connected as a system and so to effectively complete work on this program.

It is planned to perform electrical and environmental tests on the welded wire version of the timer-programmer, and when these are completed this unit will be placed on life test and the results compared with those obtained from testing the printed circuit version of this device.

B. Circuit Reliability Studies

During the next reporting period the studies involving the increase of the reliability of electronic circuitry through the application of redundancy will be continued and expanded. It is planned that digital circuits using redundant components and networks will be built and tested in the laboratory. In addition, it is expected that means can be found for effectively applying redundancy to some of the more difficult applications involving analog control system circuitry.

C. Digital Control System Circuit Development

The design and development of circuitry for a digital autopilot control system will be continued during the next reporting period. A single channel of a complete control system employing digital techniques and utilizing a MIG gyro as the signal source is currently under construction and should be completed and subjected to performance testing.

The study of circuitry applicable to advanced programmers will be continued. In this case, one of the primary objectives is to produce a

simplified reliable programmer which is capable of having its stored program modified by means of remote control. The device using core transistor logic described in this report seems promising in this application and will be investigated further.

Studies of simplified digital elements using advanced semiconductor devices such as tunnel diodes were begun during this reporting period and will be continued during the next. It is hoped that these studies will provide elements which perform digital and switching functions with a considerably fewer number of semiconductor components than those elements presently available. This should measurably contribute to the reliability of digital timer-programmers and control system circuitry.

D. Hot-Gas Servo Studies

During the next reporting period, it is planned to complete the testing of the General Electric hot-gas servo. It will then be possible to compare the mathematical model derived as a result of these tests with that obtained from the analytical studies and so to determine the validity of certain of the assumptions made in connection with the analytical studies of this device.

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